Determinants of Driver vs. Second Row Occupant Posture Modelling

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Abstract

Digital human modeling (DHM), as a convenient and cost-effective tool, is increasingly incorporated into product and workplace design. In product design, it is predominantly used for the development of driver-vehicle systems. Most digital human modeling software tools, such as JACK, RAMSIS and DELMIA HUMANBUILDER provide functions to predict posture and positions for drivers with selected anthropometry according to SAE (Society of Automotive Engineers) Recommended Practices and other ergonomics guidelines. However, few studies have presented 2nd row passenger postural information, and digital human modeling of these passenger postures cannot be performed directly using the existing driver posture prediction functions. In this paper, the significant studies related to occupant posture and modeling were reviewed and a framework of determinants of driver vs. 2nd row occupant posture modeling was extracted. The determinants which are regarded as input factors for posture modeling include target population anthropometry, vehicle package geometry and seat design variables as well as task definitions. The differences between determinants of driver and 2nd row occupant posture models are significant, as driver posture modeling is primarily based on the position of the foot on the accelerator pedal (accelerator actuation point AAP, accelerator heel point AHP) and the hands on the steering wheel (steering wheel centre point A-Point). The objectives of this paper are aimed to investigate those differences between driver and passenger posture, and to supplement the existing parametric model for occupant posture prediction. With the guide of the framework, the associated input parameters of occupant digital human models of both driver and second row occupant will be identified. Beyond the existing occupant posture models, for example a driver posture model could be modified to predict second row occupant posture, by adjusting the associated input parameters introduced in this paper. This study combines results from a literature review and the theoretical modeling stage of a second row passenger posture prediction model project.

Keywords: Vehicle Seating, Posture Prediction, Digital Human Model, Driver and 2nd Row Occupant.

1. Introduction

Over the past decades, the vehicle design process has been enhanced through the rapid development of assistant tools for the virtual design process, such as Computer Aided Design (CAD) and Computer Aided Engineering (CAE) software (Hickey et al. 1985; Summerskill et al. 2010). Automotive manufacturers gain advantage from the increasing availability and powerful functions of CAD or CAE tools (Hickey et al. 1985; Summerskill et al. 2010). Although physical prototypes or mock-ups are typically used to evaluate interaction between occupants and vehicles, they are very costly and inefficient (Bertilsson et al. 2010; Summerskill et al. 2010). In a CAD/CAE virtual design progress, a vehicle can be modelled accurately by the large amount of parts and their interaction, which reduces the needs of physical prototypes (Hickey et al. 1985; Salvendy 1997; Bertilsson et al. 2010; Summerskill et al. 2010). However, the chances of user preference testing are consequently decreased with fewer mock-ups being produced. To solve this design gap, Digital Human Modelling (DHM) systems are increasingly incorporated into the virtual vehicle design process to replace the early user testings. By utilizing DHM, issues and problems can be identified and solved in early development phases, which prevents the expensive redesign of parts for error correction in a later testing phase and reduces the timescale of the iterative design progress (Brown 1999; Summerskill et al. 2010; Svensson et al. 2010).

Although many digital human modelling software tools provide functions to predict posture and positions for drivers with selected anthropometry according to SAE (Society of Automotive

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Engineers) Recommended Practices and other ergonomics guidelines (Roe RW 1993; Salvendy 1997; Reed 1998; Reed et al. 1999; Park et al. 2000; Parkinson & Reed 2006; Howard et al. 2010; Mueller & Maier 2010; Summerskill et al. 2010; Svensson et al. 2010), there is still some limitation for users to design the whole occupant seating environment in a virtual vehicle (Summerskill et al. 2010). Only few studies have presented 2nd row passenger postural information, and the occupant package of these passengers cannot be created blindly using the existing driver's posture prediction functions. To overcome this limitation of current DHM studies, the significant studies related to occupant posture and modeling were reviewed in this paper and a framework of determinants of driver and 2nd row occupant posture modeling was extracted.

2. Materials and Methods

When sitting in a vehicle, the occupant posture is usually restricted by the design of both seat and interior (package). Beyond the anthropometric characters of the target population, the seat dimensions, positions of controls, sight line requirements, and roominess of the compartment as well as other interior layout parameters (packaging) will determine the positioning, safety and comfort for drivers or passengers (Roe RW 1993; Parkinson & Reed 2006). These determinants which are regarded as input factors for posture modeling include target population anthropometry, vehicle package geometry and seat design variables as well as task definitions (Reed et al. 1999). This paper will introduce those main determinants of the occupant posture modelling. These findings could provide a framework of the fundamental knowledge and methods required to establish a prediction model for both driver and 2nd row occupants.

2.1. Anthropometric Data

When designing the occupant package and vehicle seats, the users should be defined first (Roe RW 1993; Albert 1996). Generally, there are three anthropometric approaches to achieve the accommodation of target populations: a manikins based approach, a population model approach and the hybrid approach which combines the first two approaches (Garneau & Parkinson 2009). By using existing data of body dimensions to represent the users, the manikins based approach defines a set of boundary manikins with anthropometric extremes to represent a defined range of users. Usually, the occupant packaging and seat design guidelines use the anthropometric boundary values of 5th percentile female and 95th percentile male (Roe RW 1993; Albert 1996; Reed & Flannagan 2000; Parkinson & Reed 2006). Other seat, occupant packaging and interior design studies make use of experimentally derived preferred postures and related body dimensions of a specific sample for a detailed analysis (Roe RW 1993; Albert 1996; Reed et al. 1999; Reed et al. 1999; Reed & Flannagan 2000; Reed et al. 2000; Reed et al. 2005; Reed et al. 2006; Garneau & Parkinson 2009). This population model approach is an alternative method to accommodate users in the virtual design progress. In most cases, the hybrid approach is most popular for the whole design process. Basically, the first approach is applied in the earlier virtual design cycle and to screen the subjects who will participate in the experimental phase. The prototype produced according to the virtual design outcome can then be evaluated and validated using the second approach, making it an overall hybrid approach. The design will eventually be improved by the results of the experimental study (Roe RW 1993; Albert 1996; Reed et al. 1999; Reed et al. 1999; Reed & Flannagan 2000; Reed et al. 2000; Reed et al. 2005; Reed et al. 2006; Garneau & Parkinson 2009).

In most studies, gender, standing height (stature) and body mass (weight or BMI) are considered as basic model input associated with anthropometry of the target population. Additionally, sitting height is another critical anthropometric input to predict the sitting posture. Within the ASPECT program (i.e. the program that developed the H-Point Machine II), the ratio of sitting height to stature was also a useful input variable to predict the H-point of an occupant when sitting in either driver, front or 2nd row passenger seats (Roe R et al. 1999).

2.2. Seat Dimensions

The seat dimensions are considered as the most primary constraints of the occupant posture when sitting in the vehicle. The seat design is on the other hand based on the anthropometry of target users. The general guideline in seat design is to accommodate the majority target population, usually from the 5th percentile female to the 95th percentile male stature range (Reed et al. 1994). More specifically, Reed (Reed et al. 1994) highlights the importance to define anthropometric measurements and relate them to the seat parameter in focus. For example, hip width (anthropometric dimension) needs to relate to seat cushion width (seat parameter).

In the SAE J1100 standard, seat dimensions that restrict a human posture sitting in a vehicle are seat cushion width (W1000_X), cushion length/depth (SL9), cushion angle (A27), seat back width (W1400_X), seat back height from H-point without head restraint (H168_X), seat back/torso angle (A40) and lumbar support prominence (L81) and others (SAE 2008). For the typical adjustable seat, A27, A40 and L81 should be considered as variable input for driver, and in the future also for second row occupant posture prediction (Manary et al. 1999; Reed et al. 1999; Reed et al. 1999; SAE 2009). A detailed definition of dimensions can be found in the SAE J2732 standard or the SAE J1100 standard.

Additionally, support parameters also tend to influence the posture of a driver or occupant in general while sitting in automotive seats (e.g. lumbar support) (Reed et al. 1994). These can vary from contour measures and the orientation of the seat cushion and seatback to the location of support in the seatback (Reynolds 1993; Roe RW 1993; Reed et al. 1999). For the adjustable seat with lumbar support, it is also an important input parameter of a posture prediction modelling system.

2.3. Vehicle Interior Geometry and Occupant Packaging Design

The vehicle interior design should comply with standards and ergonomics rules. Typically, the occupant packaging design is regarded as the first task in the vehicle interior design phase, and interior design is considerably variable due to different vehicle types, for example luxury, sport, utility and others (Roe RW 1993). For different vehicle type and usage purpose, the required interior space and components arrangement and associated design should be consistent with driver and passenger positioning, in view of safety, comfort and convenience (Roe RW 1993).

In typical vehicle seat design and vehicle interior geometry design, a set of percentiled manikins needs to be developed to represent a target group of users with anthropometric extremes, and allocated in a virtual vehicle buck (Reed & Flannagan 2000). The ASPECT manikin was developed as a standard tool to support occupant packaging and seat design, auditing and benchmarking (Reed et al. 1999; Roe R et al. 1999) and later became one of the SAE standards. Figure 1 illustrates the use of the ASPECT manikin (HPM-II) to measure a vehicle seating package geometry (Reed et al. 1999).

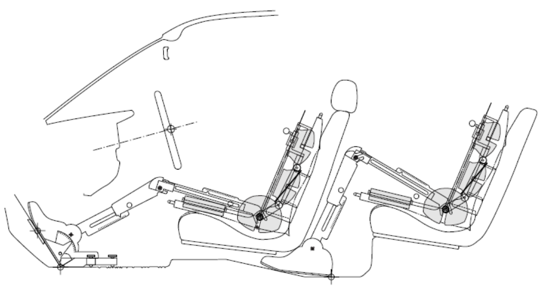

Figure 1: ASPECT manikin used to measure driver and rear seating package geometry (Reed et al. 1999)

The occupant packaging parameters include a variety of measurements: adjustment ranges of the steering wheel, seat location in reference to the floor (e.g. seat height (H30)), and the position of controls and displays to give some examples. As shown in Figure 1, beyond the seat dimensions, the occupant packaging parameters of both driver and 2nd row compartment can be measured, assessed and benchmarked by HPM II.

For the occupant packaging parameters, the differences between determinants of driver and 2nd row occupant posture models are significant, as driver posture modeling is primarily based on the position of the foot on the accelerator pedal (accelerator actuation point AAP, accelerator heel point AHP) and the hands on the steering wheel (steering wheel centre point A-Point). Figure 2 illustrates the main parameters which determine the driver posture. However, for the rear row occupant, the hands and feet are not restricted on the steering wheel and pedal. Hence, their feet, arms and hands are free to move within the rear compartment space allowance.

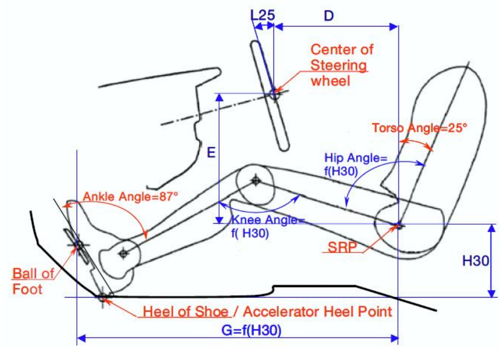

Figure 2: Basic layout with SAE 2D template (Stahlecker & Kress 2003)

The geometry of a rear seat compartment is critical for static posture prediction of a rear seat passenger (Roe RW 1993). For example, the distance between the back of the front row seat or the edge of the rear seat cushion to the occupant could influence the leg and feet positions. Additionally, the door armrest and central armrest are also factors impacting on the passenger posture in a rear seat.

Generally, the seat height (H30) variable is the most importment variable input associated with a vehicle interior package for both driver and 2nd row occupant posture prediction. Other variables' input depends on the vehicle interior design and occupant tasks.

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2.4. Driver and Passenger Tasks Definitions

Task definitions belong to the vehicle interior design and occupant package design, and task oriented anthropometric measurements are required for the occupant space design. For most studies, where these task definitions are treated as independent input from vehicle geometries, these factors are discussed separately in this section. Basically, the driver has more tasks than the rear seat passenger which relate to vehicle seating. Driving vision, steering, reaching to the controls, accelerating and braking activities need to be taken into consideration for dynamic posture simulation and prediction (Roe RW 1993; Parkinson & Reed 2006).

After investigating a number of current studies on occupant posture prediction and simulation, we found that the parameters used to predict driver posture are well defined in most studies and standards, whereby the 2nd row passenger posture is not considered. This is probably because the driver seat is typically considered much more important than the rear passenger seat in the western world. In addition, the activities of passengers in a rear seat are mostly ignored due to the limited variety of tasks that can be done in a rear compartment.

However, on general there are many passenger activities that the driver is not able to do when driving. For example, the 2nd row passenger may work or eat in the car. In this case, the passenger may prefer an upright sitting posture. For reading or talking to other passengers, in the same row or even in the front passenger seat, the passenger might prefer to adjust the seat to find a relaxed posture (Han et al. 1998). For the long distance trip, the passenger needs the seatback much more reclined to a relaxed position, in order to enjoy a better rest, listen to music or watch TV/DVD or even sleep in the rear seat. Thus, for the adjustable rear seat, to predict the passenger posture in this kind of seat, the task definition becomes an important input of the model.

2.5. Seating Posture in Vehicles

Generally, the 3D postures of a driver or passenger are recorded to represent the vehicle seating posture with respect to a vehicle coordinate system. The data is usually obtained in vehicle or laboratory environments by photographing (e.g. SAC sonic digitizer), video recording, motion capturing (e.g. VICON), palpating and probing with a 3D coordinate measurement machine (e.g. FARO arm) or other technologies (Reed et al. 1999; Reed et al. 1999; Reed et al. 2002). A set of external markers on body segments were recommended by Reed in the ASPECT project for posture recording (Reed et al. 1999). Figure 3 demonstrates the positions of the recommended landmarks and the description of each landmark.

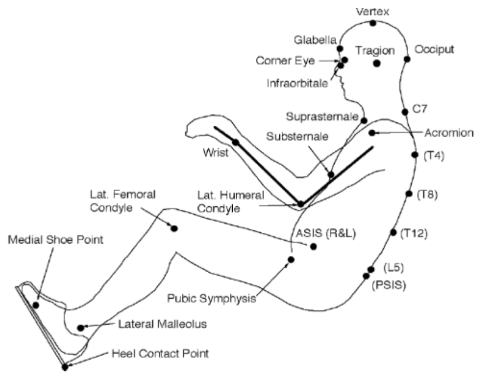

Figure 3: External landmarks to calculate related internal joints (Reed et al. 1999)

In Statistical Probability Modelling (SPM), these external landmarks are used to calculate the location of required internal joints and the related segment orientation for modeling the human posture. For instance, the hip joint center (HJC) is the most important body landmark to position the occupant in the vehicle seat, and is typically the origin point (0, 0, 0) for the 3D coordinate system of the digital human. However, the HJC cannot be measured by physical tools directly. With a pair of external landmarks on each body side, marking easily identifiable bony landmarks, the anterior/posterior superior iliac crest (ASIS and PSIS) would be measured and then the HJC will be calculated. (Reed et al. 1999; Reed et al. 1999; Reed et al. 2002)

Besides, the body segment angles include trunk (torso), hip, knee, shoulder, elbow, wrist and ankle (Figure 4) (Reed et al. 1994). Amongst others, Hanson, Sperling and Akselsson (Hanson et al. 2006) investigated the joint angle range in the sagittal plane, and reported minimum-maximum angle intervals.

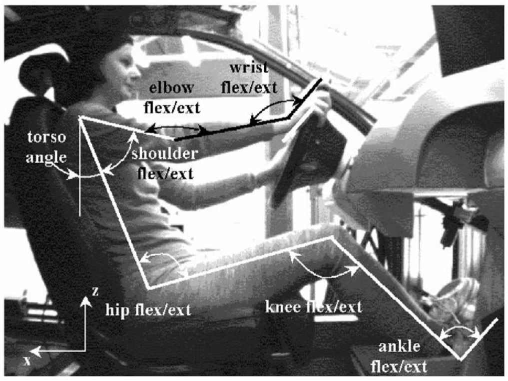

Figure 4: Driver test subject with defined joint angles (flex = “flexion:, ext = “extension”) (Hanson et al. 2006)

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The observed posture data is often linked with subjective questionnaire data, so that the preferred posture of a driver/passenger can be determined. Other models include the definitions of additional joint angles. For instance, in the ASPECT project, the trunk segment is divided into three segments: thorax, abdomen and pelvis. Consequently, the angles of thorax, abdomen and pelvis joints can be measured with the new H-Point Machine (HPM-II), developed through the ASPECT project (Reed et al. 1999; De Looze et al. 2003).

As the feet and hands of a rear occupant are not constrained by pedals and steering wheel, the posture data would be quite different from a driving posture, especially for the elbow, knee and ankle angles. In addition, the geometry of a rear compartment, such as shoulder room, arm space, knee room constrains the rear seat passenger posture significantly.

2.6. Other Factors Related to Occupant Postures

Age, driving or traveling in a passenger seat experience are factors that influence the occupant seated posture in motor vehicles (Roe R et al. 1999). In most cases, these factors are not regarded as model input in order to ease the model creation and validation.

2.7. Recent Studies of Human Posture Modelling in Vehicle Seating

Recent studies primarily focus on driver posture analysis and prediction. Only the published studies of ASPECT program (Reed et al. 1999) and Reed (Reed et al. 2005) have investigated 2nd row passenger posture in vehicles to a significant level. Table 1 provides a brief list of some recent published studies about occupant posture analysis and prediction.

Table 1: Recent studies on occupant posture analysis and prediction

(M: Male, F: Female)

Study	No. of Subjects	Anthropometric Measurements
Kinematic linkage representation of driver's posture (Reed et al. 1999)	120 M &F	Gender, Stature, Weight, Sitting Height
Cascade Prediction Model (CPM) (Reed et al. 1999)	68 M&F	Gender, Stature, Weight, Sitting Height
Subject testing in ASPECT program. (CPM) (Reed et al. 1999)	249 in total. Different amount of subjects in different development phases	17 measures in total. Stature, Weight and Sitting Height are 3 primary variables.
The effects of vehicle package, seat, and anthropometric variables on driver's posture (Reed et al. 2000)	68 M&F	As above
Assess importance of anthropometric and postural variability in selection of boundary manikins (Reed & Flannagan 2000)	96 drivers in each of 33 vehicles	As above
Optimization Prediction Model (OPM) (Reed et al. 2000)	68 M&F	As above
No posture model. Statistical analysis driving posture for Koreans (Park et al. 2000)	24 M & 19 F	10 measurements
Methods to measure in-vehicle driving postures (Jahns et al. 2001)	17 M& 7 F	26 body dimension measurements
Validating CPM model. Record the 3-D locations of 23 body landmarks. (Reed et al. 2002)	68 in model development, 120 in model validation	Gender, Stature, Weight, Sitting Height
Modelling driver reach (Reed et al. 2003)	11 M&F	Not mentioned
ATD installation in rear row of vehicle (Reed et al. 2005)	24 M&F	11 body dimensions
DHM for postal delivery vehicle designing (Reed et al. 2005)	2 manikins with 5% and 95% percentile of stature from NJANES III	No real subject involved
RAMSIS and ASPECT posture model (Archer & Kolich 2005)	11 M& 11 F	Stature, sitting height and weight

Approach to digital human motion simulation (HUMOSIM) (Reed et al. 2006)	2 JACK manikins	No real subject involved
Validation of a 3D DHM (Lee et al. 2008)	36 Koreans, 37 North Americans	Stature, weight, sitting height

3. Results

Typical input parameters of Statistical Probability Modelling (SPM) to predict the human posture in a vehicle include the anthropometry of the target population, seat variables and vehicle interior geometry variables (Reed et al. 1994; Reed et al. 1999; Reed et al. 1999; Reed et al. 2002). The most common factors that determine driver vs. 2nd row occupant posture, derived from the studies in table 1 and associated SAE J standards, are shown in Table 2, with the significant different determinants between driver and rear seat passenger highlighted in bold.

Table 2: Input parameters of driver vs. 2nd row occupant posture modelling

Input	Driver seat	2nd row seat
Anthropometrics	Gender, Stature, Weight, Sitting Height	Gender, Stature, Weight, Sitting Height
Seat dimensions	Seat Cushion Angle (A27), Back Angle (A40), Lumbar Support Prominence (L81), **Transmission Type,** Cushion Stiffness Cushion depth (SL9)	Seat Cushion Angle (A27-2), Back Angle (A40-2), Lumbar Support Prominence (L81-2), Cushion Stiffness Cushion depth (SL9-2),
Interior geometry occupant packaging	Seat Height (H30), **SW-to-BOF X (L6),** Fore-aft seat adjustment	Seat Height (H30-2), Fore-aft seat adjustment
Kinematic restrictions	SgRP (XYZ) Steering wheel (SW) center (A-Point) Y coordinate (W7), Track rise angle (A19), **SW diameter (W9), SW angle (A18), Accelerator pedal (accelerator actuation point AAP, accelerator heel point AHP (W8, H8)),** Head clearance (L38), shoulder room (W3), elbow room (W31), hip room (W5), knee clearance (L48), leg clearance (L58)	SgRP (XYZ), Track rise angle (A19-2), Head clearance (L39-2), shoulder room (W3-2), elbow room (W31-2), hip room (W5-2), knee clearance (L48-2), leg clearance (L58-2) , **Floor plane angle (A48-2)**
Task definitions	Vision, **driving,** reaching to controls, **accelerating, braking**	**Reading, working, relaxing, resting, sleeping and other tasks**
Other factors	Age, **driving experience**	Age

Table 2 only lists 4 main variable input factors associated with the target population anthropometry, which are most commonly used and overlap in most studies and SAE standards (e.g. J 4002). The number of anthropometric factors could be expanded to improve the accuracy of posture prediction.

Parameters listed in Table 2 are not all input variables for the posture prediction models. Basically, the kinematic restrictions and task definitions are constraints for the posture model. These parameters are used to develop and validate the models. For example, a driver posture modeling is primarily based on the position of the foot on the accelerator pedal (accelerator actuation point AAP, accelerator heel point AHP) and the hands on the steering wheel (steering wheel centre point A-Point). Besides, whether some of the input factors (seat, vehicle interior geometry) are variable depends on seat adjustability.

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The most common SAE standards for seat diminsions, vehicle interior geometry design and task definitions (vision, reach etc.) are listed in Table 3.

Table 3: Published SAE standards associated with vehicle seating

Standard code	Standard name
J1052_201009	Motor Vehicle Driver and Passenger Head Position
J941_201003	Motor Vehicle Drivers' Eye Locations
J1139_201003	Direction-of-Motion Stereotypes for Automotive Hand Controls
J4002_201001	H-Point Machine (HPM-II) Specifications and Procedure for H-Point Determination - Auditing Vehicle Seats
J1100_200911	Motor Vehicle Dimensions
J1516	Accommodation Tool Reference Point
J1517	Driver Selected Seat Position
J2896	Motor Vehicle Seat Performance Measures
J1050_200902	Describing and Measuring the Driver's Field of View
J128_200811	Occupant Restraint System Evaluation--Passenger Cars and Light-Duty Trucks
J826_200811	Devices for Use in Defining and Measuring Vehicle Seating Accommodation
J4003_200810	H-Point Machine (HPM-II)--Procedure for H-Point Determination--Benchmarking Vehicle Seats
J4004_200808	Positioning the H-Point Design Tool - Seating Reference Point and Seat Track Length
J2732_200806	Motor Vehicle Seat Dimensions
J287_200702	Driver Hand Control Reach
J2396	Definitions and Experimental Measures Related to the Specification of Driver Visual Behaviour Using Video Based Techniques

(Note: the datum after "_" refers to the issue date of the latest revised version of a standard)

4. Discussion

While SAE has established a significant number of standards and guidelines for ergonomic design of the vehicle driver space, the design standards for rear passenger space are limited and few studies have presented postural information of the 2nd row occupant. This applies especially to markets, where the vehicle owner is often the 2nd row occupant, especially in developing countries in Asia. Due to the lack of ergonomic design guidelines, the design of the passenger compartment can hardly be compared to the driver space design, which is considered more important in the European and American markets. Especially since China has become the largest automotive market in the world, the industries in general and particularly automotive designers have to take the Chinese market demand into consideration. As reported in automotive news (News May 4, 2010), the latest surveys and questionnaire results demonstrate that the 2nd row interior compartment and seat design has a significant impact on Chinese purchase behavior, and a large amount of vehicle owners usually occupy the seat in the 2nd row. Not only in China, but also in other Asian countries, many vehicles owners typically occupy the 2nd row seat. According to their expectations, a comfortable seating environment in the rear compartment of the vehicle is much more important than the driver's seating package, which is contradictory to the key motivation in previous design for the western auto market.

As a result, future work will require investigating the input factors for rear occupant posture prediction models, following the market trend. These posture models can then be applied to digital human modeling.

5. Conclusion

As few studies have presented 2nd row passenger postural information, digital human modeling of these passenger postures cannot be sufficiently performed. Modelling of rear row passenger posture based on existing driver posture prediction functions is impossible. In this paper, the significant studies related to occupant posture and modeling were reviewed and a framework of most important determinants of driver and rear row occupant posture modeling was identified. The determinants which are regarded as input factors for posture modeling include anthropometry data, vehicle package geometry and seat design variables as well as task definitions. The difference between determinants of driver and 2nd row occupant posture models is significant, due to different task definitions and kinematic restrictions in the rear row seat. This paper is aiming to supplement the existing parametric model for occupant posture prediction. Beyond the existing occupant posture models, a driver posture model could be modified to predict second row occupant posture, by adjusting the associated input parameters introduced in this paper. Furthermore, by utilizing the framework presented in this paper, key factors could be identified prior to posture prediction, which will shorten the design cycle and hence save time and money.

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